UM10560

230 V 7 W flyback converter SSL2101 reference board

Rev. 1 — 20 August 2012 **User manual**

Document information

Info	Content
Keywords	SSL2101, dimmable, LED driver, flyback converter, GU10
Abstract	This document describes the operation of a 230 V 7 W dimmable LED driver featuring SSL2101 and using a flyback topology. The SSL2101DB1069 reference board has a form factor that is compatible with the base of a GU10 LED lamp fitting used in Solid-State Lighting (SSL) applications.

Revision history

Rev	Date	Description
v.1	20120820	first issue

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1. Introduction

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

This document describes the operation of a 230 V 7 W dimmable LED driver featuring the SSL2101. The SSL2101DB1069 reference board has a GU10 LED lamp compatible form factor. The flyback converter topology provides a simple and efficient solution for mains dimmable LED recessed light applications.

The total input power (VA) to the board is 230 V/52 mA = 11.9 W. The SSL2101DB1069 reference board is designed to drive a 5-LED load, delivering an output power of 6.7 W with 16.3 V/410 mA.

The Power Factor (PF) is 0.75 which gives an actual input power of 0.75 × 11.9 W = 8.9 W and the resulting efficiency is 75 %.

The SSL2101DB1069 reference board complies with EMI and safety regulations.

The SSL2101DB1069 reference board is designed so the components allow enough headroom for the board to fit into a GU10 lamp base. The board dimensions are shown in Figure 1.The assembled top board view is shown in Figure 2 and the bottom board view in Figure 3.

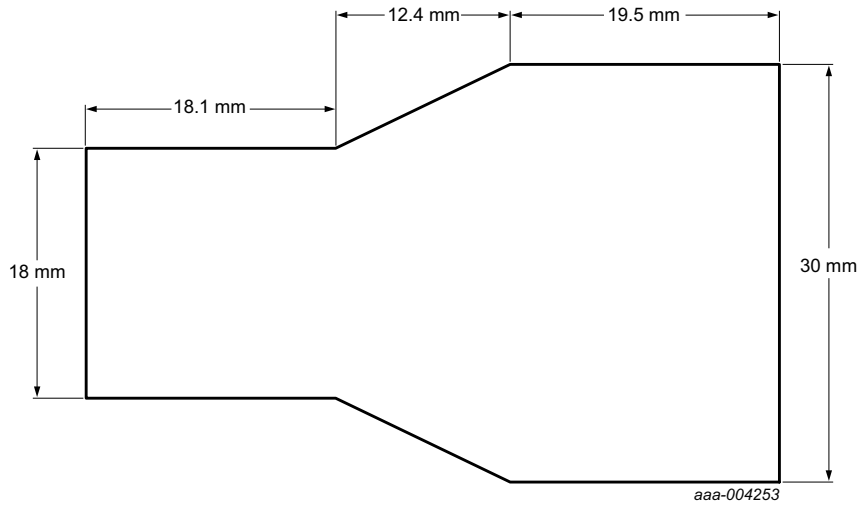

Fig 1. SSL2101DB1069 Reference board dimensions

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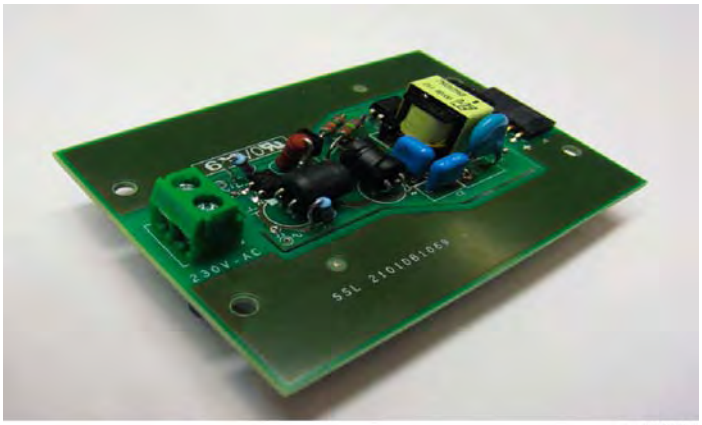

aaa-004256

Fig 2. SSL2101DB1069 Reference board (top view)

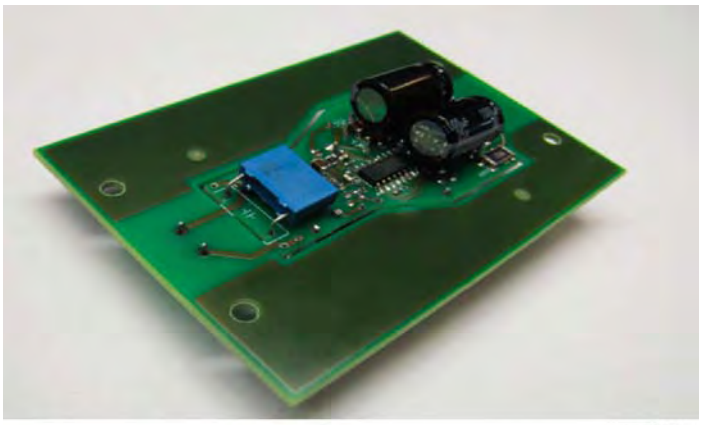

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Fig 3. SSL2101DB1069 Reference board (bottom view)

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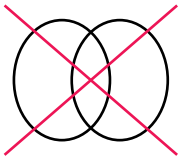
2. Safety Warning

This board is connected to the mains voltage. Avoid touching the board while it is connected to the mains voltage. An isolated housing is obligatory when used in uncontrolled, non-laboratory environments. Galvanic isolation of the mains phase using a variable transformer is always recommended.

a. isolated



b. non-isolated

Fig 4. Variable transformer isolation symbols

3. Specifications

Table 1. Specifications for the SSL2101DB1069 reference board

Symbol	Parameter	Value
V_{mains}	AC mains supply voltage	230 V
V_O	output voltage	16.3 V
I_O	output current	410 mA
$\Delta I_o/\Delta V_o$	output voltage rejection	22.5 mA/V
		(±2.5 % at nominal I_O = 410 mA)
η	efficiency	75 %
PF	Power Factor	0.75
f_{SW}	switching frequency	55 kHz

4. Functional description

4.1 General

The 230 V, 7 W flyback converter SSL2101DB1069 reference board uses the SSL2101 control IC to drive an output load of 5-LEDs. The SSL2101 is a Switch Mode Power Supply (SMPS) control IC with an integrated MOSFET. Detailed information about the SSL2101 operation is contained in the *SSL2101 SMPS IC for dimmable LED lighting data sheet*.

The converter operates in Discontinuous Conduction Mode (DCM).

The SSL2101DB1069 reference board is triac dimmable and can be used in combination with most leading and trailing-edge dimmers. During dimming, the rectified mains voltage is averaged and attenuated and supplied to both the PWMLIMIT and BRIGHTNESS pins of the SSL2101. This voltage reduces the converter duty cycle and frequency and, as a result, the LED output current.

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Dimming compatibility performance has been tested with a selection of 30 leading/trailing-edge dimmers as shown in Section 7.

5. SSL2101DB1069 reference board connections

The GU10 LED driver SSL2101DB1069 reference board takes a 230 V, 50 Hz mains supply and supports a 5-LED load. The board connection is shown in Figure 5.

Remark: Make all connections with the input power is switched off.

- Connect the 5-LED load as output load together with power meter at both inputs and outputs.
- Connect V_{IN} (230 V/50 Hz) using an isolating transformer to the input connection points of the buck converter. Alternatively use an AC power supply with limited output current capability (for example; 200 mA).
- Increase V_{IN} to 230 V and measure the different parameters as shown in Table 2.
- When testing dimmer compatibility, connect a leading or trailing edge dimmer between V_{IN} and the buck converter input connection points.

Remark: Use protective a shield over application and never touch the board when measuring or testing.

Table 2. Input/output parameters

V_{IN} (V)	I_I (mA)	PF	P_{IN} (W)	V_O (V)	I_O (mA)	P_O (W)	η
230	52	0.75	8.9	16.3	410	6.7	0.75

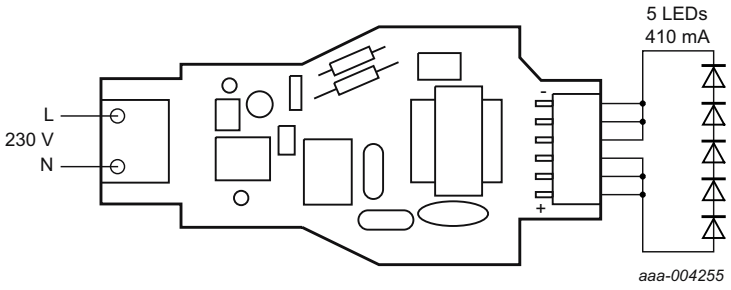

Fig 5. Connection to the SSL2101DB1069 reference board

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6. Performance data

The performance was measured with 5 LEDs connected as output load. The performance data is shown in Figure 6 to Figure 10.

6.1 Efficiency

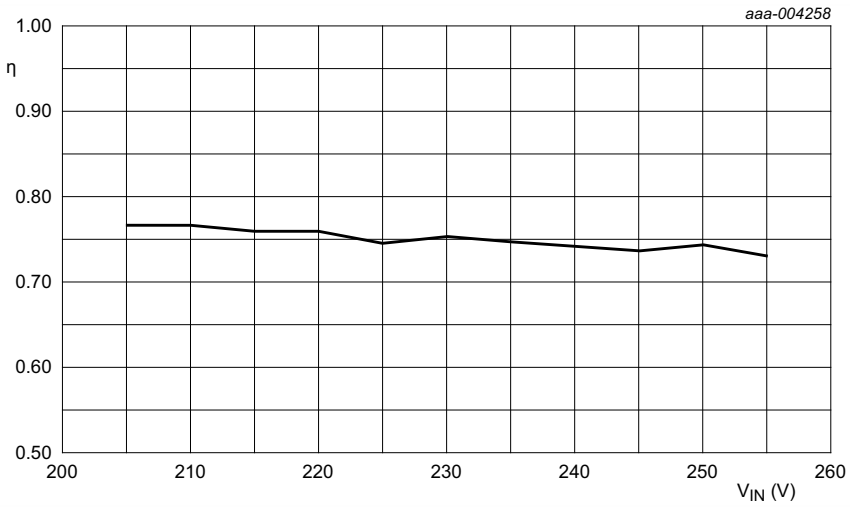

Fig 6. Efficiency as a function of AC mains input voltage

6.2 Line regulation (0.5 %/V)

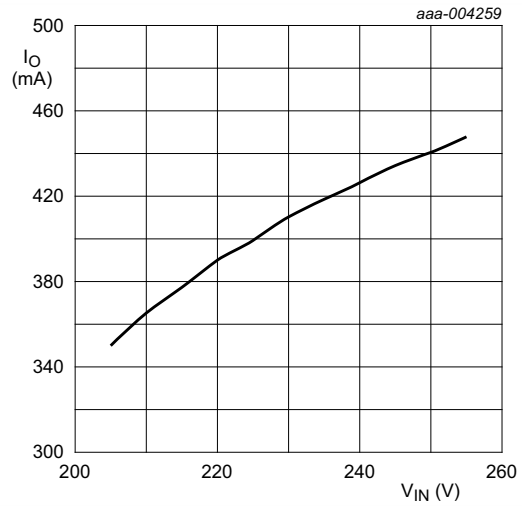

Fig 7. Output current as a function of AC mains input voltage

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6.3 Power factor

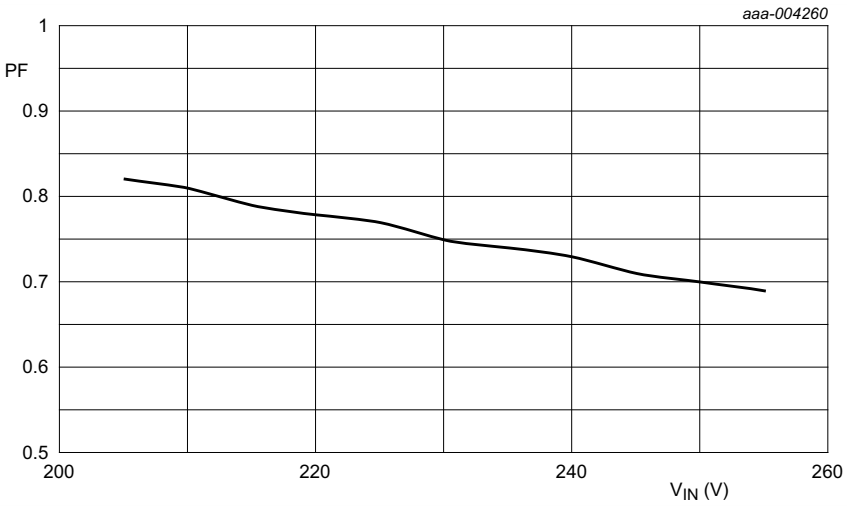

Fig 8. Power factor as a function of AC mains input voltage

6.4 Load regulation (±2.5 % per volt for nominal I_O = 410 mA)

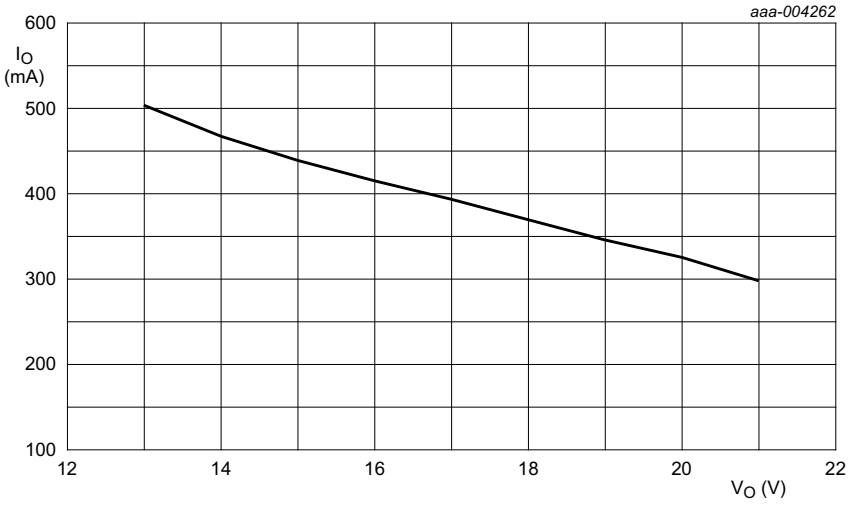

Fig 9. Output current as a function of output voltage

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6.5 Electromagnetic Interference (EMI)

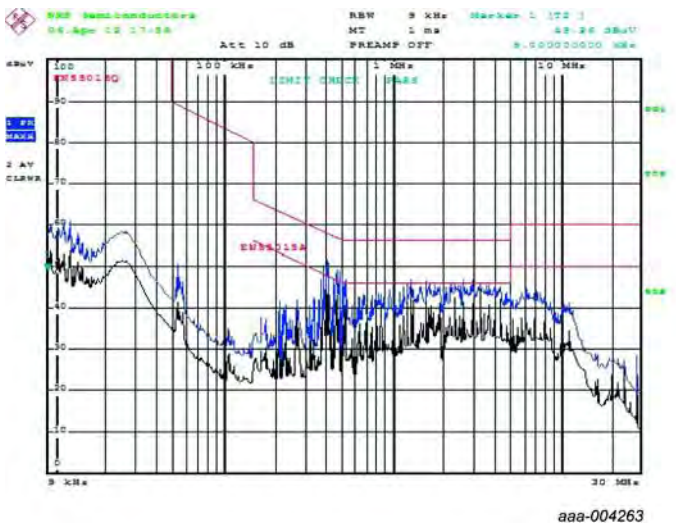

Fig 10. EMI performance

7. Dimming compatibility and characteristic

Dimming compatibility is defined as having smooth dimming without any flashing or flickering effects occurring across the complete dimming range. The SSL2101DB1069 reference board has tested with a selection of trailing and leading-edge dimmers as shown in Table 3.

7.1 Dimming compatibility

Table 3. Selection of dimmers tested

Due to different manufacturer dimmer specifications, the dimming compatibility may vary
With no triac (no dimming) the LED output current is 410 mA which represents 100 %

Manufacturer	Dimming range	Dimming compatibility
Leading-edge		
Opus 852390	0.25 % to 100 %	good
Opus 852392	0.25 % to 100 %	good
Bush 2250U	0.1 % to 100 %	good
Bush 2247U	5 % to 100 %	good
Bush 6519U	23 % to 100 %	good
Gira 118400	0.25 % to 100 %	good
EverFlourish PF0700DA	1.2 % to 100 %	good
HET 3901	0.25 % to 100 0	good
Legrand CXM03	0.1 % to100 %	good
Varilight 1103034	0.1 % to 100 %	good
Chinese dimmer 1	0.8 % to 100 %	good
Chinese dimmer 2	0.9 % to 100 %	good

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Table 3. Selection of dimmers tested *...continued*

Due to different manufacturer dimmer specifications, the dimming compatibility may vary
With no triac (no dimming) the LED output current is 410 mA which represents 100 %

Manufacturer	Dimming range	Dimming compatibility
Legrand V051	0.1 % to100 %	good
Chinese dimmer 3	6.5 % to 100 %	good
Chinese dimmer 4	6 % to 100 %	good
Trailing-edge		
Drespatronic 0817	11 % to 100 %	good
Drespatronic 0815	5 % to 100 %	flicker
Berker 286170	9 % to 100 %	good
Berker 2874	10 % to 100 %	good
Bush 6591U	0.25 % to 100 %	triac on/off
Bush 6513U	23 % to 100 %	good
Jung 225TDE	9 % to 100 %	good
Jung 243EX	10 % to 100 %	good
Gira 030700	10 % to 100 %	good
PEH433HAB	11 % to 100 %	good
Niko	23 % to 100 %	good
Legrand CXM02	5 % to 100 %	triac on/off at 100 %
Legrand 78402	7 % to 100 %	good
Varilight 1106037	3 % to 100 %	good
CLIPSAL Universal dimmer	7 % to 100 %	good

7.2 Dimming characteristic

At 230 V input mains, the voltage divider sets the voltage on the BRIGHTNESS and PWMLIMIT pins and therefore the converter frequency and duty cycle. This divider consists of resistors R7, R8 and R9, together with capacitor C9 for filtering,

During dimming, the voltage on the BRIGHTNESS and PWMLIMIT pins decreases. This decrease reduces the converter frequency and duty cycle respectively.

The dimming curve of I_O against the triac conduction angle for leading and trailing edge dimmers is shown in Figure 11.

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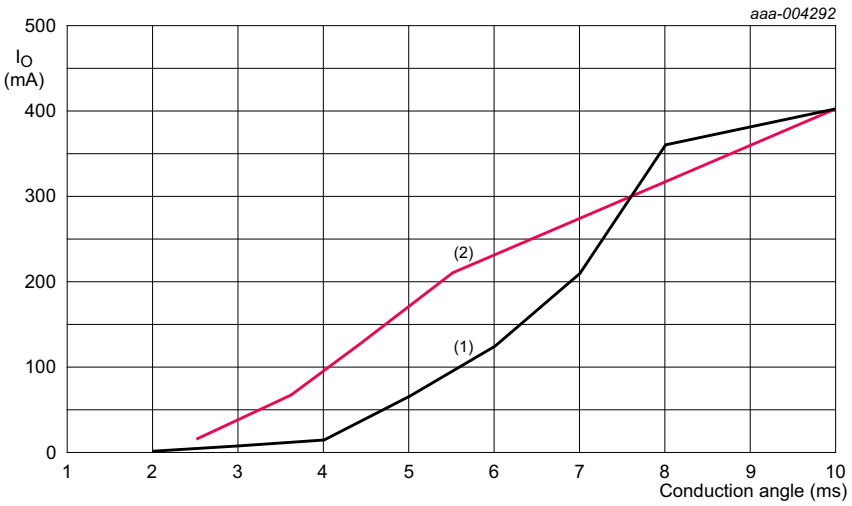

(1) Leading-edge dimmer

(2) Trailing-edge dimmer

Fig 11. Dimming curve - LED current as a function of triac conduction angle

The SSL2101DB1069 reference board uses the feedback loop on the secondary side to limit the LED output current. Resistors R18 and R18a sense the LED current I_O. A current mirror using the BC847S compares I_{LED} to a reference current I_{REF}. V_O, R21, R24 and R23 set this current. When $I_O > I_{REF}$, the extra current in the optocoupler limits the on time of the converter.

The same feedback loop is also used for overvoltage protection (OVP). OVP begins once V_O is greater than the Zener voltage of D8, which here is 20 V. The dimming voltage is detected by sensing the average rectified voltage.

After R and R8 limit the double bridge rectifier and the input peak current, capacitors C2 and C3 determine the triac latch current. The mains voltage and current waveforms for a leading-edge dimmer for a conduction angle of 8 ms ($\phi = 4\pi / 5$) are shown in Figure 12.

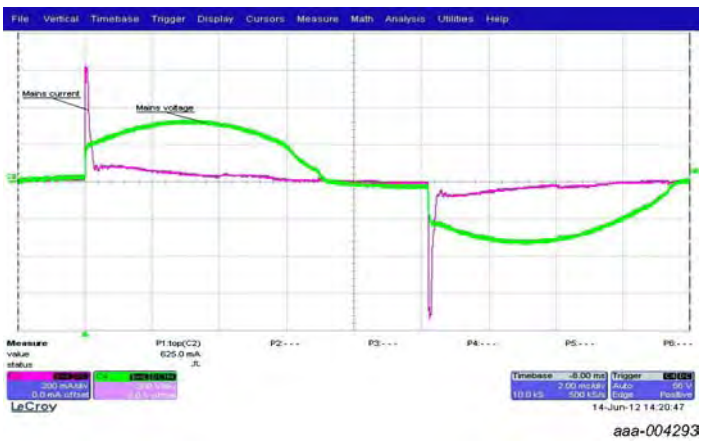

Fig 12. Mains voltage/current waveforms

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To maintain sufficient triac current over the dimming range, the SSL2101 has two internal current sinks called bleeders. The strong bleeder SBLEED resets the zero crossing of the dimmer and also helps triac latching.

The weak bleeder WBLEED is used to maintain sufficient hold current after the triac latches and throughout the complete dimming range.

SBLEED is switched on when the maximum voltage on the WBLEED and SBLEED pins is below 52 V.

WBLEED is switched on when the voltage on the ISENSE pin is greater than −100 mV (that is, between 0 mV and −100 mV).

The ISENSE voltage is derived from the voltage drop across R17 and thus the converter current return to the double bridge rectifier.

In this application, an optional circuit is included for extra hold current. The hold current flows through Q1 and R6 when WBLEED is on. The resistor R6 determines the extra current required for good dimming compatibility but there is a compromise with efficiency. The weak bleeder is switched off when the ISENSE voltage exceeds −250 mV. The weak bleeder is also switched off when the strong bleeder is switched on.

Example:

The weak bleeder is switched on when the current in the converter return path is less than 20 mA. This condition could be a minimum requirement for the hold current of the triac dimmer.

The 20 mA current through R17 = 10 Ω results in a voltage of −250 mV at RGND node with respect to ground. R15, R16 and C9 attenuate and filter this voltage and supply it to the ISENSE pin of the SSL2101.

When R15 and R16 = 10 kΩ, the voltage at ISENSE is −100 mV with respect to ground. This voltage is the internal threshold level to switch on the WBLEED. In this case, the weak bleeder is switched on when the converter current is less than 20 mA.

7.3 Power losses

For an input mains voltage of 230 V, the measured powers are P_{IN} = 8.9 W and P_O = 6.7 W. The power loss is 2.2 W which is distributed over the following elements:

- input resistors R and R8 (300 mW)
- SBLEED resistor R3 when the internal SBLEED is operational (50 mW)
- WBLEED resistors R4 and R5 and extra current through Q1 and R6 when the internal WBLEED is operational (600 mW)
- core and copper losses in the transformer T1 (400 mW)
- snubber circuit D2 and D3 (100 mW)
- MOSFET (conduction and switching losses are 300 mW)
- secondary diode D4 (450 mW)

The hotspot of the PCB is at resistor R6 which is an extra bleeder current to improve dimming compatibility. The value here is a compromise between efficiency and dimming compatibility.

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The measured temperature of R6 is 75 °C at 25 °C ambient. Reduction in temperature is possible by replacing R6 with a series or parallel connection of two resistors having the same total equivalent resistance value.

The measured temperature of the transformer is 55 °C at 25 °C ambient.

Finally, the power loss as a function of triac conduction angle for a leading-edge dimmer over the complete dimming range is shown in Figure 13.

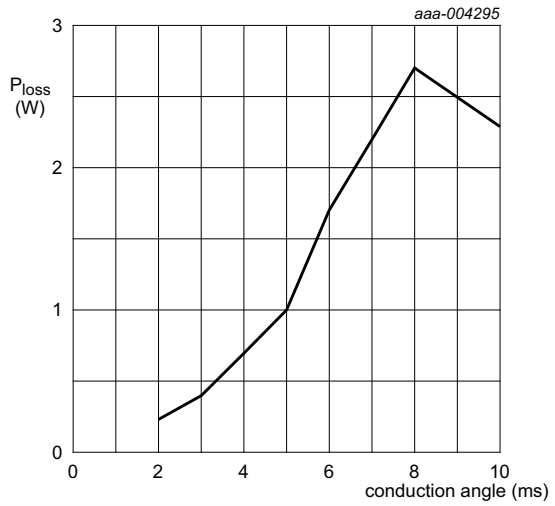

Fig 13. Power losses as a function of conduction angle

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7.4 Schematic

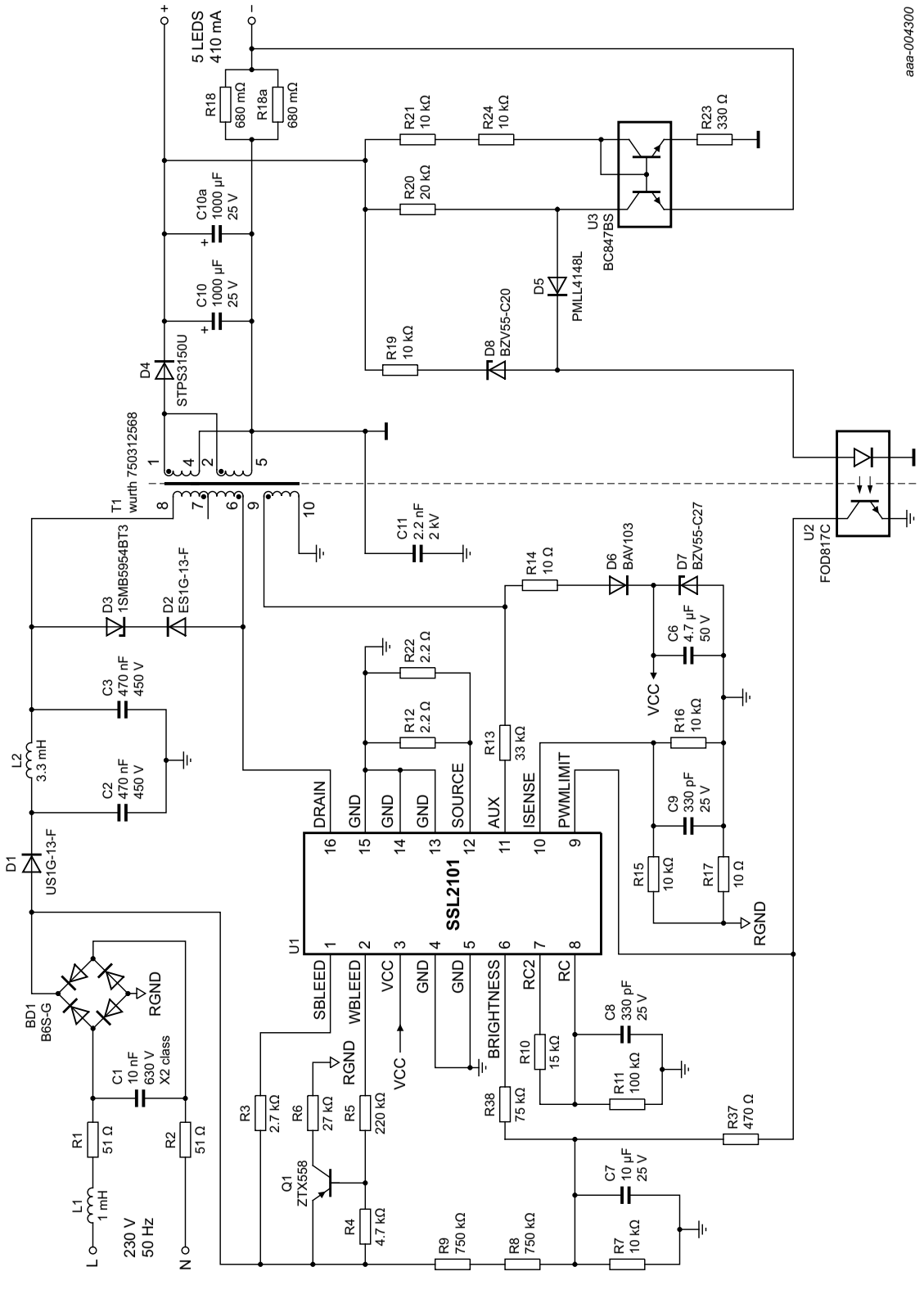

Fig 14. Schematic diagram: 230 V 7 W flyback converter using the SSL2101

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8. Bill of Materials (BOM)

Table 4. Bill of Materials

Part Reference	Description	Manufacturer/part number
BD1	bridge rectifier; 600 V, 0.8 A	Comchip Tech; B6S-G
C1	0.010 μF; 305 V (AC); 630 V (DC); 20 %; X2 class; radial; long lead	EPCOS; B32921C3103M
C2	0.47 μF; 450 V (DC); 10 %; epoxy coated ceramic; radial	Murata; RDED72W474K5B1
C3	0.47 μF; 450 V (DC); 10 %; epoxy coated ceramic; radial	Murata; RDED72W474K5B1
C6	4.7 μF; 50 V; 10 %; X5R ceramic; 1206	Taiyo Yuden; UMK316BJ475KL-T
C7	10 μF; 25 V; 10 %; X7R ceramic; 1206	Taiyo Yuden; TMK316B7106KL-TD
C8	330 pF; 25 V; 5 %; COG (NPO); 0603	AVX; 06033A331JAT2A
C9	330 pF; 25 V; 5 %; COG (NPO); 0603	AVX; 06033A331JAT2A
C10	1000 μF; 25 V; 20 %; electrolytic; radial (10x16)	Panasonic - EEUHD1E102
C10a	1000 μF; 25 V; 20 %; electrolytic; radial (10x16)	Panasonic - EEUHD1E102
C11	2.2 nF; 2 kV; 10 %; radial	Murata; DEBB33D222KA2B
D1	fast diodes; 400 V, 1 A; DO214 AC	Diodes Inc.; US1G-13-F
D2	fast diodes; 400 V, 1 A; DO214 AC	Diodes Inc.; ES1G-13-F
D3	Zener; 160 V; 3 W; SMD	On-Semi; 1SMB5954BT3
D4	Schottky; 150 V; 3 A; SMB	STM; STPS3150U
D5	switching diode; SOD80C	NXP Semiconductors; PMLL4148L
D6	small signal diode; SOD80C	NXP Semiconductors; BAV103
D7	Zener diode; 27 V, 500 mW; SOD80C	NXP Semiconductors; BZV55-C27
D8	Zener diode; 20 V, 500 mW; SOD80C	NXP Semiconductors; BZV55-C20
J1	wire connection; 0.6 mm	-
J2	wire connection; 0.6 mm	-
J3	wire connection; 0.6 mm	-
J4	wire connection; 0.6 mm	-
J5	receptacle 2.54 mm single 6-way	SAMTEC; SSW-106-02-G-S-RA
J6	MKDSN 2.5/2-5.08	PHOENIX CONTACT; 1888687
L1	1 mH; radial	Murata; 22R105C
	1 mH; radial (alternative)	Würth Elektronik; 744732102
L2	3.3 mH; radial	NXP Semiconductors; SSL2101
	3.3 mH; radial (alternative)	Würth Elektronik; 7447724332
Q1	PNP 400 V, 200 MA TO92-3	Diodes/Zetex; ZTX558
R1	51 Ω; 0.6 W; 1 %; axial	Vishay; MRS25000C5109FCT00
R2	51 Ω; 0.6 W; 1 %; axial	Vishay; MRS25000C5109FCT00
R3	2.7 kΩ; 0.25 W; 5 %; axial	Panasonic - ECG; ERD-S2TJ272V
R4	4.7 kΩ; 0.1 W; 5 %; 0603	Panasonic - ECG; ERJ-3GEYJ472V
R5	220 kΩ; 0.25 W; 5 %; axial	Panasonic - ECG; ERD-S2TJ224V
R6	27 kΩ; 2 W; 5 %; axial	Vishay; PR02000202702FR500

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Table 4. Bill of Materials *...continued*

Part Reference	Description	Manufacturer/part number
R7	10 kΩ; 0.1 W; 5 %; 0603	Panasonic - ECG; ERJ-3GEYJ103V
R8	750 kΩ; 0.25 W; 1 %; 1206	WELWYN; WCR1206-750KFI
R9	750 kΩ; 0.25 W; 1 %; 1206	WELWYN; WCR1206-750KFI
R10	15 kΩ; 0.1 W; 5 %; 0603	Panasonic - ECG; ERJ3GEYJ153V
R11	100 kΩ; 0.1 W; 5 %; 0603	Panasonic - ECG; ERJ-3GEYJ104V
R12	2.2 Ω; 0.25 W; 1 %; 1206	Vishay; CRCW12062R20JNEAIF
R13	33 kΩ; 0.1 W; 5 %; 0603	Panasonic - ECG; ERJ-3GEYJ333V
R14	10 kΩ; 0.1 W; 5 %; 0603	Panasonic -ECG; ERJ-3GEYJ100V
R15	10 kΩ; 0.1 W; 1 %; 0603	Panasonic - ECG; ERJ-3EKF1002V
R16	20 kΩ; 0.1 W; 1 %; 0603	Panasonic - ECG; ERJ-3EKF1002V
R17	10 kΩ; 0.5 W; 5 %; 1210	Panasonic - ECG; ERJ-14YJ100U
R18	680 kΩ; 0.5 W; 1 %; 1206	YAGEO; RL1206FR-7W0R68LI
R18a	680 kΩ; 0.5 W; 1 %; 1206	YAGEO; RL1206FR-7W0R68LI
R19	10 kΩ; 0.25 W; 1 %; 0603	Vishay; CRCW060310K0FKEAHP
R20	20 kΩ; 0.1 W; 1 %; 0603	Vishay; CRCW060320K0FKEA
R21	10 kΩ; 0.25 W; 1 %; 0603	Vishay; CRCW060310K0FKEAHP
R22	2.2 Ω; 0.25 W; 1 %; 1206	Vishay; CRCW12062R20JNEAIF
R23	330 Ω; 0.25 W; 1 %; 0603	Vishay; CRCW0603330RFKEAHP
R24	10 kΩ; 0.25 W; 1 %; 0603	Vishay; CRCW060310K0FKEAHP
R37	470 Ω; 0.1 W; 5 %; 0603	Bourns; CR0603-JW-471GLF
R38	75 kΩ; 0.1 W; 1 %; 0603	Multicomp; MC 0.063 W 0603 1 % 75 K
T1	L_{pri} = 1.67 mH; $n_{pri/sec}$ = 7.438; $n_{pri/aux}$ = 5.789	Würth Elektronik; 750312568
U1	SMPS controller IC for driving LED applications; SO16	NXP Semiconductors; SL2101
U2	optocoupler; 300 % CTR; Through pin	Fairchild; FOD817C
U3	NPN/NPN transistor; SOT363	NXP Semiconductors; BC847BS

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9. PCB layout

The board has a star connection for the different return grounds paths back to the ground plane of SSL2101, therefore avoiding ground loops. A PCB layout example is shown in Figure 15 and the actual PCB layout is shown in Figure 16 and Figure 17.

Important aspects of layout:

- Connection of power and signal ground must be at the ground plane of SSL2101 (all the GND pins) and with sufficient vias.
- The primary current loop area is minimized and consists of:
  - C2, L2, C3 bus line to the RC pin of the transformer
  - pin 6 of the transformer to the BRIGHTNESS pin of SSL2101
  - source resistor R12, R22 to ground plane at IC
  - power ground plane return to C2, L2, and C3

  The DRAIN pin of SSL2101 must be very near to pin 6 of the transformer. The pin also requires a separate power ground return from source resistor R12 and R22 to C2 and C3.
- Snubber diodes D2 and D3 must be very close in parallel to pins 8 and 6 of the transformer also resulting in a minimum current loop.
- The secondary current loop area is minimized and consists of:
  - pins 1 and 2 of transformer to diode D4
  - diode D4 to capacitors C10 and C10a
  - ground of capacitors C10 and C10a to secondary ground plane at pins 4 and 5 of the transformer.
- Place the oscillator components R10, R11 and C8 close between the oscillator pins RC2 and RC, and the GND pins (4, 5) of the IC.
- Separate return path from SSL2101 ground plane using the R17 resistor to ground of the bridge rectifier.
- Separate ground return path of the auxiliary winding (pin 10 of T1) to SSL2101 ground plane and minimize this current loop.
- Separate ground return of R7 and C7 to SSL2101 ground plane.
- I_{SENSE} components C9 and R16 have separate ground return to SSL2101 ground plane.
- Place optocoupler U2 and isolation capacitor C11 close to each side of the transformer. The optocoupler signal and ground are supplied symmetrically to pins 9, 4 and 5 respectively. If possible, use a separate ground return path from the optocoupler ground to the GND pins of the SSL2101. The Y2 capacitor C11 must have a separate ground return path to power ground.

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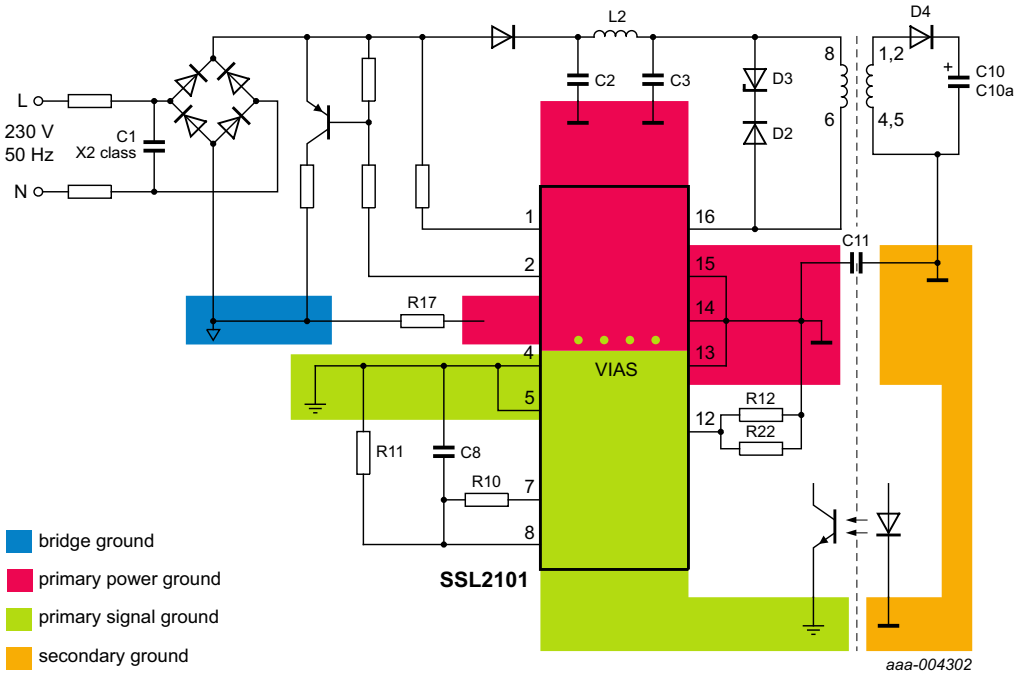

Fig 15. PCB layout example

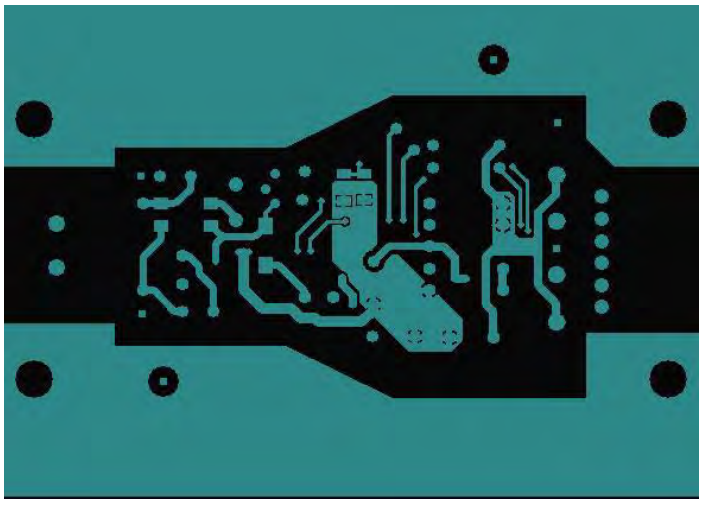

Fig 16. PCB layout (top view)

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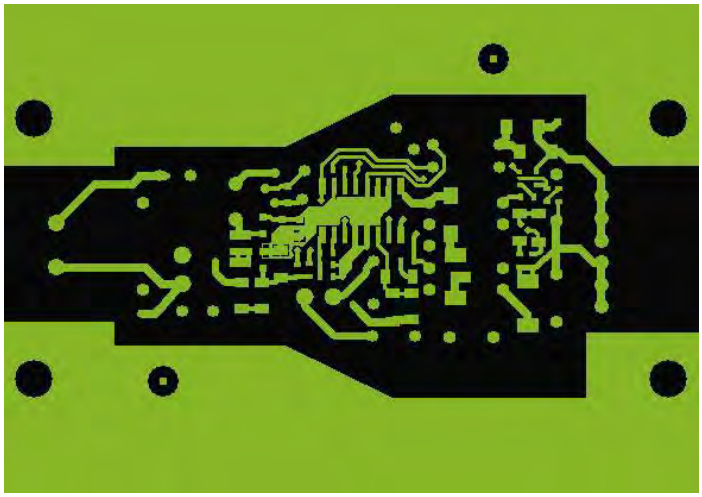

aaa-004303

Fig 17. PCB layout (bottom view)

10. Inductor specification

The SSL2101DB1069 reference board is designed for functional isolation. An EE13/6/6 coil former is used to allow sufficient headroom when the SSL2101DB1069 reference board is mounted into a GU10 lamp base fitting.

When testing or doing measurements, use a protective shield over the application and never touch the board.

If transformer reinforced isolation is required, the following methods can be adopted:

- flying secondary leads with triple-isolated wire
- elevated transformer with triple-isolated wire
- EE13/12/6 coil former (bobbin) with triple-isolated wire

Remark: The PCB design has reinforced insulation by having a 1 mm air gap on the PCB between the primary and secondary of the transformer.

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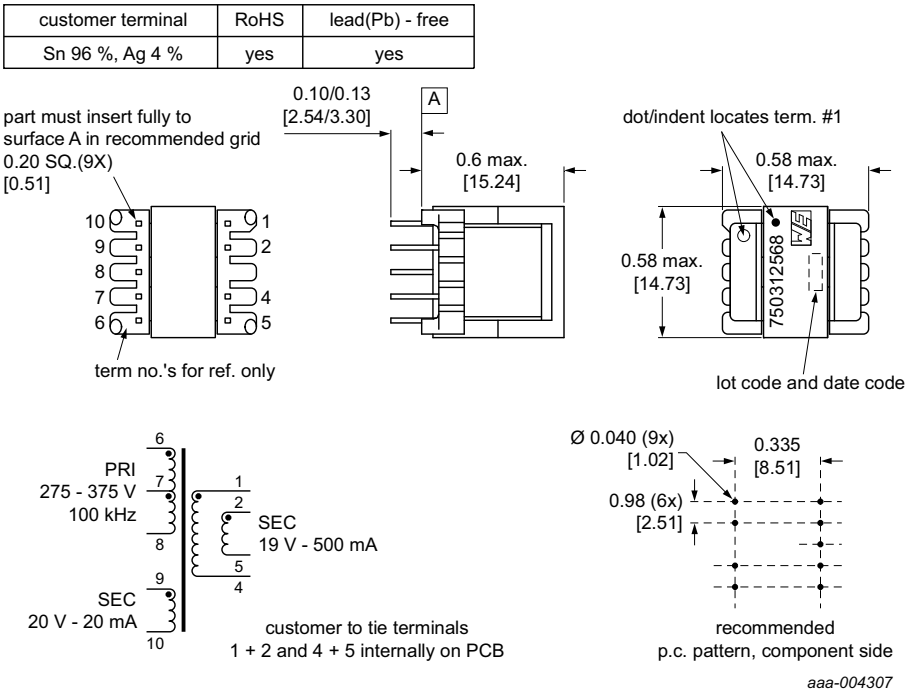

Fig 18. Inductor Specification

Table 5. Electrical specification

All values are specified at 25 °C unless otherwise specified. All values without tolerance are typical values. Functional insulation for a primary circuit at a working voltage of 400 V (DC)

Parameter	Value	Comment
DCR (6 to 8)	2.9 Ω, ±10 %	-
DCR (1 to 5)	78 mΩ, ±10 %	short-circuit 1 to 2 and short 4 to 5
DCR (9 to 10)	520 mΩ, ±10 %	-
Primary Inductance (6-8)	1.67 mH, ±10 %	100 mV, 10 kHz
Leakage Inductance (6-8)	13 μH, ±10 %	short-circuit1 to 2 to 4 to 5 and short-circuit 9 to 10 100 mV, 10 kHz
Primary saturation current	400 mA	-
Turns ratio 6 to 7: 7 to 8	1 : 1.017, ±1 %	-
Turns ratio 6 to 8: 1 to 4	7.438 : 1, ±1 %	-
Turns ratio 6 to 8: 2 to 5	7.438 : 1, ±1 %	-
Turns ratio 6 to 8: 9 to10	7 : 1, ±1 %	-
Dielectric rating primary to secondary (1 to 10)	4 kV applied for 1 s	Short 4 to 5 and 8 to 9

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